Title:
Ontologies-Based Knowledge Representation Method for Improving Learning Performance in The Engineering Drawing Course

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Introduction:
The engineering drawing (ED) course plays a pivotal role in facilitating effective communication within the engineering field, offering a visual language that transcends linguistic barriers. As an integral component of engineering design, this course provides a fundamental skill that forms the basis for understanding and expressing intricate design concepts, ensuring precision in engineering project execution [1-2]. The ED course empowers students to translate abstract ideas into tangible representations, establishing a crucial link between theoretical knowledge and practical application. Proficiency in engineering drawing is essential for creating, reading, and accurately interpreting engineering documentation, blueprints, and schematics—critical skills for professional engineers [3]. Within the University Engineering Curriculum System, engineering drawing holds paramount importance as a foundational skill set. The incorporation of engineering drawing into the curriculum not only provides students with a crucial technical skill but also nurtures a mindset that values precision, innovation, and excellence in the dynamic realm of engineering [4].

Despite its paramount role in the university engineering curriculum, the engineering drawing course poses significant challenges for many undergraduate students majoring in engineering, creating obstacles in the learning process. Specifically, these challenges may arise from various factors: A primary obstacle faced by students in the ED course is the struggle to master basic concepts of geometric drawing, coupled with a lack of necessary imagination capabilities, creative thinking, observation, and inquiry skills [3]. Moreover, in most university engineering curriculum settings, the ED course follows a hierarchical design, requiring students to build understanding from one concept to another; thus, difficulties in grasping basic ED concepts make learning at subsequent levels more challenging [5]. Additionally, the meticulous attention to detail and precision required in engineering drawing demands patience and persistence, qualities that not all students may possess abundantly. Furthermore, the course often involves acquiring specific technical skills, such as understanding various projection methods and mastering intricate drafting techniques, which can be overwhelming for those not naturally inclined toward technical disciplines.

Several innovative strategies have been implemented to enhance the teaching and learning of engineering drawing, with the goal of improving students' performance in this crucial course [3-5]. One particularly noteworthy approach involves integrating the introduction and coaching of computer-aided design (CAD) tools and other three-dimensional prototyping software, such as SolidWorks and Pro-engineering. These tools not only facilitate the creation of accurate and detailed drawings but also offer a more interactive and engaging learning experience. Additionally, some virtual prototypes used in the ED course can be reconstructed using these computer-aided tools, aiding students with limited spatial abilities in better understanding and interpreting complex geometric features during the learning process. Furthermore, the adoption of project-based learning or problem-based learning (PBL) has gained popularity, providing students with opportunities to apply theoretical concepts in real-world scenarios, thereby reinforcing their understanding and skill development related to the ED course [4]. While these techniques focus on incorporating new elements, such as knowledge and practical experience with CAD software and PBL tasks, for practicing acquired theoretical knowledge about engineering drawing in lecture settings, there is still a lack of feasible methods to assist students in understanding and acquiring abstract knowledge and skills related to the theoretical unit on descriptive geometry.

To address this gap, this paper introduces a novel knowledge representation method designed to assist students in comprehending and acquiring theoretical knowledge, specifically in the realm of descriptive geometry. It accomplishes this by analyzing knowledge correlations through the application of fundamental ontological principles. The subsequent sections of the paper are structured as follows: A concise literature review is conducted to summarize existing studies and initiatives related to proposing innovative teaching and learning methods for the engineering drawing course, as well as ontologies-based knowledge representation for fostering innovative education and other courses relevant to the engineering drawing curriculum. The framework of the proposed method is detailed, with several cases illustrating how the ontology-based approach is applied to represent theoretical knowledge in the engineering drawing (ED) course. Following this, the proposed method is introduced to students during the ED course lecture to aid in memorizing and understanding theoretical knowledge of descriptive geometry. Subsequently, students using the proposed method form the experimental group, which is compared with the control group, which consists of students without experience with the proposed method. A comprehensive test is conducted to validate the proposed method by comparing the results of the experimental and control groups. Finally, the paper concludes with a discussion of findings in the result analysis.

Main Idea:

Ontology is widely used as a means to formalize domain knowledge, making it accessible, shareable, and reusable [6]. Various specific types of ontology-based knowledge models support engineering design [7]. The content of these ontologies differs based on engineering design needs; however, they share several basic components to capture subject features in three aspects [8]: Objects exist in the real world; Objects have properties and attributes that can take values; Objects exist in various relations with each other. Due to its main features, ontology is an ideal approach to represent various concepts and heterogeneous knowledge faced by engineering undergraduates in the course of engineering drawing. However, there is seldom a focus on this topic. To fill this gap, this paper aims to help improve the learning performance of engineering students in the ED course by educating them to apply the proposed ontology-based approach during their learning process. The teaching method and procedure are then explained in detail to ensure students acquire ontology-based knowledge representation. Afterward, a test is organized to validate the practical function of the proposed ontology-based knowledge representation by comparing the performance of the experimental group and their peers in the control group. The outline and basic ideas of each subsection are explained as follows.

The framework of the proposed ontology for the ED course

The main framework of the proposed ontology for representing knowledge in the ED course is illustrated in Fig. 1. Based on the fundamental ideas of ontology, there are primarily three types of entities that form the entire knowledge graph of the ED course. The first type is the concept entity, which plays a significant role in formulating the theoretical system of the ED course. Meanwhile, the problem entity serves as the building block for applying theoretical knowledge in real engineering training or projects. The third type of entity is the procedure, which involves the main steps to solve problems using concepts and serves as a bridge between the other two types of entities.

Different types of entities in Fig. 1 include a set of sub-entities with their lists of attributes. Specifically, the entity of the problem mainly consists of a set of typical elemental problems to formulate a synergistic problem in real practice or exercise books, usually through combination. In short, a complicated problem in the exercise or practice can be divided into several elemental problems. Similar to the entity of the problem, the concept entity involves a hierarchy of concepts at various abstraction levels; moreover, each abstraction level has its attribute set. The third entity is the procedure, which mainly consists of specific steps to resolve problems in exercise or practice. In general, the procedure entity only has three main steps: the first step is problem analysis to decompose the problem to be solved into several elemental problems; the second step may take the form of an iteration sequence to solve each elemental problem one by one; the third step synergizes solutions to all elemental problems and formulates the whole solution.

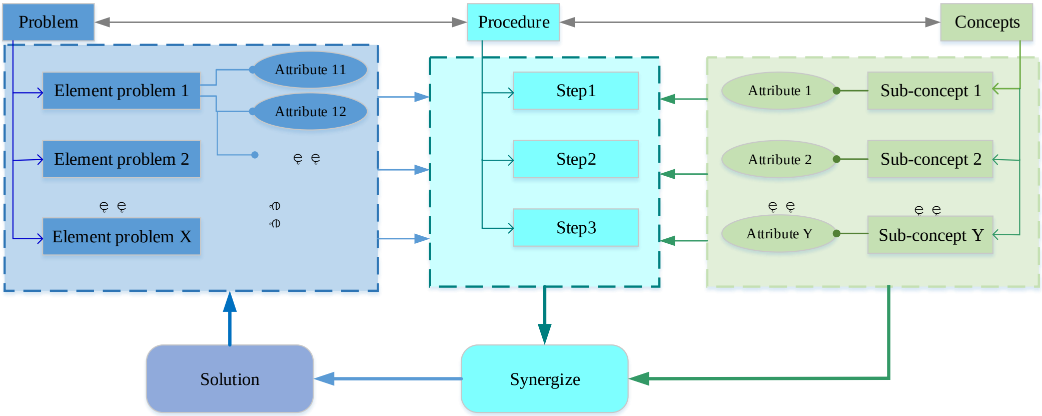
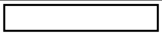
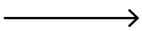


Fig. 1: The framework of the proposed ontology-based representation.

The process of educating students to handle the ontology-based representation

It is unrealistic for students to manage all three types of ontologies within the limited time of the ED course. Compared with the specific theoretical structure, students are more concerned about the final scores they can acquire at the end of the course. Moreover, it is more useful to help students understand the fundamental ideas of ontology for their future studies rather than focusing on acquiring the proposed three types of ontology. In this regard, the teaching technique mainly takes the form of exemplar typical problems; in other words, the ontology for the problem is initially taught to students to help them understand the fundamental ideas and elements of the ontology.

A specific example of the ontology-based representation designed to educate students is shown in Fig. 2, with the ontological building elements in Tab. 1. Referring to Fig. 2, the exemplar problem is represented as a whole entity at the most abstract level, and this entity involves a set of sub-entities at lower abstract levels. The part geometry of the exemplar problem is about the combined result of several simple basic geometries through Boolean operations; thus, entities at different abstract levels are connected. Moreover, basic geometries can be further divided into faces, lines, and points in space. All these geometric elements are entities at different abstract levels. These entities have several attributes, including the value of the three-dimensional Cartesian coordinate, dimensional annotation, dimensional/geometric tolerance, materials, and surface roughness—all of which are important technological specifications in the ED course.

Symbols					
Names	Entity	Sub-entity	Attribute	Connection	Subordination
Examples	Mechanical part body (Bearing	Basic geometry (Cylinder)	Size (Dimensions)	Boolean operation (Boolean	Belonging (connection between

	support)			addition)	attribute and entity)

Tab. 1: Building elements of the proposed ontology-based representation.

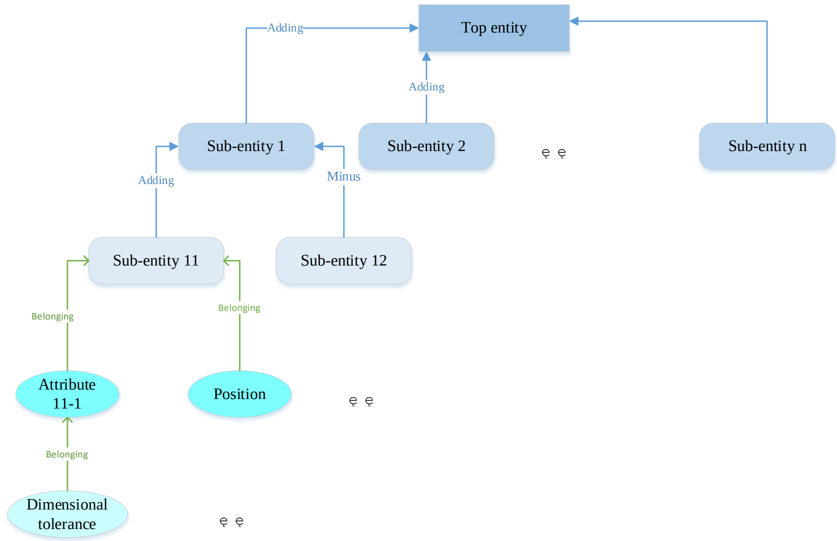


Fig. 2: Exemplar ontology-based representation for students to learn.

Experiment designed for the validation of the proposed ontologies as the teaching method

In order to verify the workability of the proposed ontology-based representation in the improvement of students' learning performance on the ED course, an experiment will be organized as the following steps:

Step 1: recruit appropriate participants

The participants recruited for the experiment are first-grade students majoring in engineering disciplines related to mechanical engineering. They have not been exposed to any knowledge about the ED course or ontology before. Given the significance of the ED course for their future professional careers, it is considered one of the most crucial core courses. Students are motivated to learn the ED course with the goal of achieving higher scores. From this perspective, these students are ideal participants for the experiment designed to test the ontology-based representation. A total of 50-60 participants are expected to be recruited for this experiment.

Step 2: Experiment conditions setting

All recruited participants are randomly divided into two groups, with 25 to 30 participants in each group. One of the two groups is chosen as the control group, while the other group is the experimental group. Participants in the experimental group will be required to attend a specific lesson in which the ontology-based representation will be taught; in contrast, participants in the control group will not receive any information about the proposed representation. Subsequently, both groups will be required to complete a test paper involving several complicated ED problems in different classrooms on their own within a specific time frame. Moreover, participants will be required to note the time spent on solving each problem. Their answer sheets will be collected when the test is finished. Following that, a questionnaire with several questions about students' comments on the test and the proposed method will be filled out by all participants. It is worth noting that the questionnaire for the experimental group will have several additional questions about comments on the usability of the proposed ontology-based representation.

Step3： Measuring indicators for the validation

The learning performance of students in the ED course will be measured using a set of indicators listed in Table 2. Referring to Table 2, there are four indicators: the first one is swiftness, which measures how quickly participants finish the test; the second indicator is correctness, which measures the quality of participants' learning performance. The first two indicators are obtained by analyzing the results of participants' answer sheets. The third indicator is the difficulty of the test, as remarked by all participants from both the experimental and control groups, using a five-point Likert scale. The fourth indicator is the comment on the usability of the proposed ontology-based representation, collected from participants in the experimental group using a five-point Likert scale.

Indicators	*Scale*	*Guidance for use*
Swiftness	0-60(min)	Remarked time when finished all the test
Correctness	0-100 (points)	Quality of learning performance measured by test scores of all the participants
Difficulty	Five-point Likert scale (1,3,5,7,9)	1 stands for the simplest, 9 for the hardest, 5 for the medium, 3 for relatively simple, and 7 for relatively hard
Usability	Five-point Likert scale (1,3,5,7,9)	1 stands for the least useful, 9 for the most useful, 5 for the medium, 3 for relatively useless, 7 for relatively useful

Tab. 2: Measuring indicators for the experiment to be organized.

Step 4: Analysis of results by comparing two groups

The final step aims to validate the usability of the ontology-based representation in improving the learning performance of the ED course by comparing the results of the experimental participants with those of the control group. Moreover, the effectiveness of the proposed method can be further assessed by comparing it with the augmented reality (AR) assistant tool, as shown in Fig. 3, which can be conducted as a supplement to the main study.

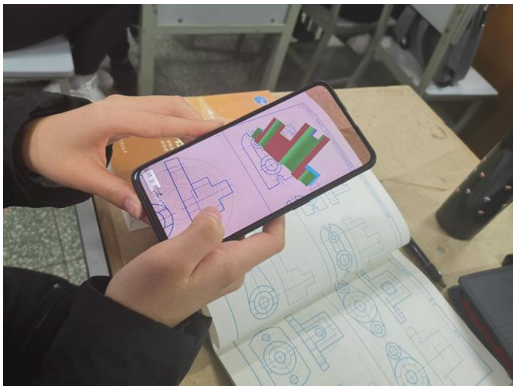


Fig. 3: AR assistant learning tool for the ED course.

Brief Discussions:

Compared with existing studies, the benefits of the proposed method are supported by experimental results, which are shown in three following aspects:

Firstly, using the proposed ontology-based knowledge representation significantly improves students' learning performance in the ED course. This is supported by the notably higher scores, both in overall scores and the seven checkpoints, observed in the experimental group compared to the control group.

Secondly, the proposed ontology-based knowledge representation is not only useful but also user-friendly for students to apply in practice. This is evidenced by the positive comments collected from participants in the experimental groups through questionnaires.

Thirdly, there is no apparent correlation between the mastery of the proposed representation and the learning performance in the ED course. In other words, students who are more proficient in using the proposed representation may not demonstrate better performance than those who are less proficient in using the proposed modeling methods. Therefore, it is advisable to recommend the proposed ontology-based knowledge representation for undergraduate students to use in learning the ED course. Additionally, the proposed knowledge representation can be utilized as a pre-test module before tackling complex ED tasks, such as drawing assembly graphs.

Conclusion:

This study aims to introduce a novel ontology-based representation approach for instructing engineering undergraduates in the ED course. The framework of the proposed method involves three types of entities that interact with each other. The usability of the proposed approach is validated through an experiment designed to measure participants' learning performance in the ED course using a set of indicators. Further evidence can be revealed through the analysis of results concerning the factors that influence learning performance in the ED course.

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